

The Resonance and Magnetic Rotation Spectra of Sodium Vapor Photographed with the Concave Grating.

BY
FELIX E. HACKETT

DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS
HOPKINS UNIVERSITY IN CONFORMITY WITH THE REQUIRE-
MENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY



BALTIMORE
1909

THE RESONANCE AND MAGNETIC ROTATION SPECTRA OF SODIUM VAPOR PHOTOGRAPHED WITH THE CONCAVE GRATING

BY R. W. WOOD AND FELIX E. HACKETT

The fluorescence and magnetic rotation of sodium vapor have been the subject of an extensive investigation by one of the present writers.¹ This paper deals with the further study of the phenomena under a higher dispersion than has been hitherto employed. In order to set forth more clearly the scope of the present investigation, a short account of the results which have been obtained in the previous work will be given, but for further information original papers must be consulted.

The fluorescent spectrum of sodium vapor excited by white light consists of a region in the orange-red and another in the greenish-blue with a broad double band in the position of the D lines. When the vapor is dense, the spectrum in the red is seen to be distinctly banded. In the course of the present work it was found that the red and orange lines of lithium excite fluorescence in the red, but as these are the only monochromatic sources thus far found which do so, it has not been possible to make a detailed study of this region. A large number of metallic arcs, however, have been found capable of causing fluorescence in the greenish-blue. In some cases several lines in the arc are active, but wherever it was possible to isolate an exciting line, the spectrum of the fluorescence was found to be comparatively simple and to consist of widely separated lines, most of which were placed at nearly equal intervals along a normal spectrum. In the earlier work, a three-prism spectrograph was used and the wave-lengths could not be determined within 2 Å. U. with the dispersion which it gave. The intervals varied between 34 and 38 Å. U. Later work has shown that the intervals are still more constant, averaging 38 Å. U.

¹ Wood and Moore, *Astrophysical Journal*, **18**, 94, 1903; Wood, *Philosophical Magazine*, **12**, 499, 1906.

The vibrating system in the atom in the present case has such a constitution that it is capable of absorbing monochromatic radiation of a certain frequency and re-emitting a great part of it as radiation of the same frequency, combined with other related frequencies. The phenomenon may be considered as a case of light resonance. On this account it seems well to call the fluorescent spectra due to monochromatic stimulation resonance spectra. Light re-emitted without change of wave-length we may call resonance radiation. The simple relation existing between the wave-lengths in these spectra makes them a most interesting addition to the phenomena of radiation. The series which have been discovered in the emission spectra of the elements have more complex formulae, and the inference that the members of one series form part of the same electro-mechanical system, though very plausible, has been disputed. But the lines in the resonance spectra must belong to the same system since they are all due to single exciting lines. It is of great importance to know the exact law connecting their frequencies, for this is a characteristic of the type of the system. As Professor Larmor has pointed out, a non-radiating system of electrons in steady orbital motion when disturbed by the absorption of a radiation corresponding in frequency to the frequency of one of the electrons should then emit radiations consisting of equidistant frequencies, whose spacing was equal to the frequency of the period of the orbital motion. This holds in general for any dynamical system of particles which form a rotating ring. Further it has been shown by Stephenson¹ that any dynamical system, in which the restoring force is a periodic function of the time, will give forced oscillations with equidistant frequencies. He has put forward such a system as a model for the sodium atom in regard to fluorescence. These results have greatly increased the interest of the present work of determining more exactly the wave-lengths of the fluorescent lines. The earlier work had still left it open to question whether the apparent equi-spacing of wave-length is an exact law, or is only a first approximation to a more complicated relation such as an equi-spacing of frequencies as exists in the above-mentioned dynamical system.

It may be stated here that the present values for the wave-lengths

¹ *Philosophical Magazine*, 14, 115, 1907.

have fully confirmed the first opinion that the regularity in the resonance spectra was an equi-spacing of the *wave-lengths* of the series.

These relations between the wave-lengths in the fluorescence alone would be a very incomplete contribution to the data necessary for the solution of the problem of constructing a model of the radiating mechanism in the atom which gives the fluorescence. It is also necessary to have some information about the elements which are vibrating. The Zeeman effect along the lines of force in the magnetic field has shown that a great many lines in the emission spectra of the elements are due to the vibration of negative electrons and this inference has been implicitly extended by many writers to all spectral lines. The direction of the magnetic rotation at an absorption band also serves to yield similar information for absorption bands. From the theory of this phenomenon it has been shown that the magnetic rotation at the D lines in sodium vapor is due to negative charges. The same is true at the ultra-violet lines which with the D lines form the principal series as shown by one of us.¹ A more extended investigation of the magnetic rotation spectrum has enabled some conclusions to be drawn concerning the nature of the vibrating system for nearly all the fluorescent lines.

When plane-polarized white light is passed through sodium vapor in a magnetic field along the lines of force, a nicol prism, set to extinction in the absence of the magnetic field, will now transmit a brilliant orange-yellow light. When this light is analyzed in the spectroscope it is seen to consist of a great number of bright lines in the greenish-blue and red with a narrow bright region of continuous spectrum near the D lines. The latter is simply the normal magnetic rotation of all the region of the spectrum near the D lines and has been the subject of a previous investigation.²

The lines in the red and green make up the magnetic rotation spectrum. It has been shown that they are narrow regions, possibly less than a tenth of an Ångström unit wide, in which the light has been rotated through varying degrees, enabling it to pass through the

■ ¹ Wood, *Philosophical Magazine*, **10**, 408, 1905; **14**, 145, 1907; **15**, 274, 1908.

² Wood, "The Ultra-violet Absorption, Fluorescence, and Magnetic Rotation of Sodium Vapour," *ibid.*, **18**, 530, 1909.

nicol. An account has been given of the attempts which have been made to determine the direction and magnitude of the rotation in these lines. Success was finally attained by using a Fresnel double quartz prism in combination with two nicols. A full account of the method has already been given. By this means it was discovered that the magnetic rotation spectrum in the red consisted in part of lines rotated in the same direction as the D lines and in part of lines rotated in the opposite direction. The simplest conclusion would be to say that the latter are due to the vibrations of positive electrons. This is a point, however, which must be considered as unsettled at the present time. In the present work the foregoing method was used both in the red and green. The method is quite successful in the red, and the wave-lengths of the magnetic rotation lines in this region have been measured and their direction of rotation determined. In the green the method was not so successful, and another method was devised which has given the direction of rotation of the lines in this region also. The wave-lengths of the principal rotations have already been obtained from photographs with the 14-foot grating. The spectroscope used in the present investigations gave a brighter spectrum and a great many additional lines were obtained. These lines have enabled the scheme of five series, drawn up in the earlier paper, to be greatly extended. The improvement in the measurement of the wave-lengths of the resonance spectra has brought out more clearly relations existing between the magnetic rotation and the fluorescence, so that it has been possible to infer whether the series in the resonance spectra are due to negative electrons or not.

APPARATUS

We shall now proceed to a detailed account of the investigation and a description of the several spectra.

There has been no essential modification of the apparatus used in the previous investigations. The sodium vapor is heated in an exhausted steel tube thirty inches long and three inches in diameter with its ends closed by plate-glass cemented with sealing wax, the ends of the tube being cut slightly oblique, so as to avoid reflection from the plates. A steel retort at its center, in which a large amount of sodium can be stored, was made from a piece of short steel

tubing (which could just slip into the long tube), by fitting a circular disc with an oval aperture at its center to each end. Additional sodium could easily be introduced into the retort, without removing it from the tube, through the aperture by means of a pointed brass rod. The tube was exhausted by means of a Fleuss pump and heated by a large burner; the ends were kept cool by tightly wound coils of lead piping through which cold water circulated. A short column of strongly heated sodium vapor was thus obtained in the retort, from which it slowly diffused through the aperture, condensing on the colder walls of the tube before it reached the glass windows.

The exciting beam of light was brought to a focus just within the retort, and the fluorescence viewed against a black background obtained by smoking the second window. A small silvered glass mirror about 1 cm square placed before the first window deviated the fluorescent light through an angle of 90° from the direction of the exciting beam of light and it was concentrated by means of a short-focus lens on the slit of the spectrograph.¹ This consisted of a 12-foot concave grating, ruled with 14,438 lines to the inch, used with a 6-foot collimating lens. With this combination the focal curve at the camera was practically a straight line within the region under investigation, so that it was possible to use plates. As the most important region of the fluorescence in the green lies at about $\lambda = 5100$, the grating was turned so that this region fell near the center of the plate. The plate-holder was 8 inches long and the region which could be photographed on one plate extended from 4500–6500. The camera was fitted with the usual rotating shutter device, for obtaining the comparison iron spectrum above and below the fluorescent spectrum.

On account of the greater dispersion, the fluorescent spectra were now much fainter than before and long exposures were necessary, extending in many cases to 20 hours. It was very important therefore to obtain the brightest possible fluorescence. As yet no exact investigations on this subject have been made, but a few general considerations may be mentioned. Pressure, temperature, and intensity of the exciting light are the three important factors. Fluorescence takes

¹ This materially increased the effective intrinsic intensity of the fluorescence as it now appeared strictly "end-on" when viewed in the mirror.

place only at low pressures and continues to increase in brightness with decreasing pressure. This was still noticeable when the pressure was reduced from 4 mm to 2 mm, the lowest pressure which could be obtained with the Fleuss pump, and which was the pressure used in the present work.

The fluorescence increases with increasing temperature, but it is evident that in this case a certain maximum will be reached. But even if this maximum is not reached, it must be noticed that the range of temperature which can be used depends on the dimensions of the apparatus and the efficiency of the water-jacket at the ends of the tube. The sodium vapor streams out from the retort gradually, condensing on the walls. It is necessary that the temperature-gradient along the tube should be great enough to cause all the vapor to condense before it reaches the glass window. Otherwise a white deposit forms on the windows and fogs them. For this reason a single large burner gave as high a temperature as could be safely employed, and if slightly displaced from the center a fog was sure to form on the nearer window after some time. The cold-water jackets cannot prevent this if the source of heat is too near one end, since there is a radial heat-gradient as well as a longitudinal one, and the former may be very large in a wide tube. The higher the temperature of the sodium vapor the longer the tube which must be used, and consequently the smaller the angular aperture of the glass window viewed from the retort. This limits the amount of light which can be thrown into the retort so that in this way there is not much advantage in raising the temperature after a certain stage is reached.

The fluorescence takes place through the whole path of the beam of light in the vapor, but it is brightest where the light rays converge to a focus. As most arcs wander over the electrodes, this bright spot of fluorescence is continually moving to and fro, causing a corresponding motion of the image on the slit. If the image be small, it may be for a great part of the time to one side or the other of the slit, so that the actual exposure is but a fraction of the apparent exposure. The fluorescent spot must then be large enough so that some part of the image will always be on the slit. Again the fluorescence takes place through the volume of the vapor, so that the best results with a given source would be obtained by having the maximum concentra-

tion through the volume and not only at a single point. Both conditions are satisfied if we form a large image of the arc in the retort, utilizing the full aperture of the tube. In practice the best working-conditions were obtained by trying several adjustments and different lenses to condense the light.

Where metallic arcs were obtained by using a cored carbon filled with the salt or metal as anode, it was sometimes necessary to prevent the glowing carbon from exciting white-light fluorescence in the retort. This was done either by placing an asbestos screen with a horizontal slit just in front of the arc, or by focusing the arc on a small hole in a screen, and throwing the image of this hole by means of a second lens into the retort. In the latter case the wandering of the arc could be observed on the screen, and correction made by moving it from side to side. In the former case an image of the arc was thrown on a screen behind the arc which served the same purpose.

Cramer's Instantaneous Isochromatic plates were exclusively used in photographing the fluorescence in the green, as they were found to be superior to any others which were tried, on account of their high and fairly uniform sensibility in this region. As even with the brightest fluorescence produced by monochromatic stimulation the plates were considerably underexposed, they were slightly fogged by a short exposure of 10 sec. at a distance of three feet from a very small gas flame and then strongly developed. The advantage of treating photographs of weak spectra in this way has recently been discussed and illustrated.¹

SILVER EXCITATION

The results which have been obtained for each excitation will be discussed in detail and, at the end of the paper, a chart of all the series which have been obtained and a general summary of the relations of the different series will be given. We begin with the resonance spectrum due to the silver arc in which there is only one exciting line, λ 5209. The photograph with the 12-foot grating has recorded only six lines, though in the earlier work fifteen were obtained. But the new measurements of these six lines show a much more regular spacing. This is seen in the second column of the table, in which the

¹ Wood, *Astrophysical Journal*, 27, 379, 1908.

differences between successive members of the spectrum is given. If we regard the fluorescence as a forced resonance due to the exciting line, then it is the relation of the different wave-lengths in the spectrum to the wave-length of the exciting line which is of interest. The almost constant spacing suggests that the wave-lengths can be represented approximately by the formula $\lambda = \lambda_0 \pm mk$, where λ_0 is the wave-length of the exciting line and k is the common difference and m is a natural number, 1, 2, 3, etc., which fixes the place of the line in the series. The value of k obtained by taking the difference between the exciting line and any other line is given in column III. The result of using the average value to calculate the wave-lengths of the series is given in column V.

I	II	III	IV	V
			m	$5209.6 \pm m \ 38.2$
5133	38.2	$76.6 = 38.3 \times 2$	2	5133.2
5171.2	38.4	$38.4 = 38.4 \times 1$	1	5171.4
5209.6	38.3	Exciting line	0	5209.6
5247.9	37.8	$38.3 = 38.3 \times 1$	1	5247.8
5285.7	37.7	$76.1 = 38.05 \times 2$	2	5286.
5323.4		$113.8 = 37.9 \times 3$	3	5324.2

The regularity which exists in the series is brought out almost equally well by the figures in any of the three columns, II, III, and V. The arrangement in the third column is preferable since it prevents a double discrepancy arising from an error in one wave-length and it is adopted in the tables for the other series. Instead of calculating the wave-lengths, the average value of the common difference, k , will simply be given.

Ten of the fifteen lines in the photograph of the spectrum obtained in the earlier work seem to fit into the series given above, the remaining four belong obviously to quite a different series. As these additional lines will be included also on the chart, a full table is given below. The series to which the exciting line belongs is marked *a* and the second series *b*; as there is no exciting line in this series, the shortest wave-length is taken as origin. The differences are not so constant as in the present determinations, especially in the first five lines, which are very faint and could not be measured with great accuracy.

Their position is shown on the chart (Plate X) on which intensities

are roughly represented by the length of the lines. In the case of the silver excitation the dotted lines are from measurements made on the earlier plate.

SILVER EXCITATION

Intensity	Wave-Length	Series <i>a</i> , $k=38$	Series <i>b</i> , $k=38$
I.....	4947.5? <i>a</i>	261.5 = 7 × 37.4	
I.....	4985.3? <i>a</i>	223.7 = 6 × 57.3	
I.....	5022.3? <i>a</i>	186.7 = 5 × 37.3	
I.....	5059.5? <i>a</i>	149.5 = 4 × 37.5	
I.....	5097 ? <i>a</i>	112 = 3 × 37.3	
2.....	5122 <i>b</i>		
6.....	5133 <i>a</i>	76 = 2 × 38	
2.....	5160 <i>b</i>		38 = 1 × 38
8.....	5170.8 <i>a</i>	38.2 = 1 × 38.2	
4.....	5198 <i>b</i>		76 = 2 × 38
10.....	5209 <i>a</i>		
2.....	5236 <i>b</i>		114 = 3 × 38
8.....	5247 <i>a</i>	38 = 1 × 38	
6.....	5285.7 <i>a</i>	76 = 2 × 38	
4.....	5323.4 <i>a</i>	117.5 = 3 × 39.1	

In the scale of intensity adopted throughout this paper 10 denotes the intensity of the exciting line and the relative intensities of other lines are expressed by numbers from 10 to 1.

LEAD EXCITATION

In the lead resonance spectrum, which is also excited by a single line λ 5006.1, there is a second series which is almost as strong as the principal series. In other words, a series of doublets is excited as has previously been shown to be the case with cadmium λ 5086. But these two series do not by any means include the whole twenty-seven lines which appeared on the plates. Some of these apparently can be arranged in a series as shown in the table on p. 348, but with a very much smaller spacing than is usual; for this reason this grouping can be regarded as tentative only. As the appearance of a second and even a third series, in addition to the principal series which includes the exciting line, occurs in most monochromatic stimulations, it will be convenient to include all these series under the general term of secondary series. Their differences given in the tables will be in general reckoned from the wave-length of the shortest member of the series. The lines on the original photograph are too narrow and faint to reproduce well. Their position is shown on the chart.

A cored carbon filled with metallic lead was used for the lead arc. By properly adjusting the current and size of the hole in the carbon, the arc could be kept playing between metallic lead and carbon cathode, and it showed no tendency to strike on to the carbon. The current used was about 7 amperes and the hole was 6 mm in diameter in a carbon rod whose diameter was 12 mm. The carbon became red hot and burned away until it formed only a narrow rim surrounding a bath of molten lead. As it burned away at the same rate as the lead evaporated, the arc when the carbon was once filled needed very little attention and ran very smoothly.

LEAD EXCITATION

Intensity	Wave-Length	Series a. $k=39$	Series b. $k=39$	Series c. $k=37.5$
2.....	4929.4 <i>a</i>	77.1 = 2×38.5		
1.....	4964.4 <i>b</i>			
2.....	4967.5 <i>a</i>	39 = 1×39		
2.....	5003.4 <i>b</i>		39 = 1×39	
10.....	5006.5 <i>a</i>			
2.....	5042.4 <i>b</i>		78 = 2×39	
8.....	5045.2 <i>a</i>	38.7 = 1×38.7		
2.....	5049.7			
6.....	5081.5 <i>b</i>		117.1 = 3×39	
6.....	5084.2 <i>a</i>	77.7 = 2×38.9		
4.....	5121 <i>b</i>		156.6 = 4×39.2	
4.....	5123.7 <i>a</i>	117.2 = 3×39.1		
4.....	5158.5 <i>b</i>		194.1 = 5×38.8	
4.....	5162.4 <i>a</i>	155.9 = 4×39		
2.....	5196.4 <i>c</i>			
6.....	5202.4 <i>a</i>	195.9 = 5×39.2		
1.....	5226.3			
2.....	5233.4 <i>c</i>			37 = 1×37
2.....	5240.4 <i>a</i>	233.9 = 6×39		
1.....	5266.9			
3.....	5272.1 <i>c</i>			75.7 = 2×37.8
2.....	5278.8 <i>a</i>	272.3 = 7×38.9		
3.....	5300.4			
1.....	5309.7 <i>c</i>			113.3 = 3×37.8
1.....	5337.3			
1.....	5365.6			
1.....	5372.2			

BARIUM EXCITATION

The barium line $\lambda 4934$ excites a beautiful series of equally spaced lines shown on Plate XI, Fig. 8, and in Fig. 13 with a portion of the magnetic rotation spectrum (14) in coincidence with it. The lines resemble the divisions on a centimeter scale, so regular is their spacing. The line $\lambda 4934$ is the bright line at the left of the plate. In addition

BARIUM EXCITATION

Intensity	Wave-Length	Series a. $k=38.8$	Series b. $k=38.4$
10.....	4554. <i>x</i>		
6.....	4562.1 <i>x</i>		
6.....	4574.6 <i>x</i>		
6.....	4580.3 <i>x</i>		
6.....	4599.2 <i>x</i>		
4.....	4606.9 <i>x</i>		
2.....	4673.8 <i>x</i>		
6.....	4691.5 <i>x</i>		
6.....	4726.5 <i>x</i>		
2.....	4756.8 <i>x</i>		
2.....	4761.2 <i>x</i>		
4.....	4860.9 <i>a</i>	73.3 = 2×36.7	
2.....	4863		
4.....	4896.8 <i>a</i>	37.4 = 1×37.4	
2.....	4900.5 <i>x</i>		
10.....	4934.2 <i>a</i>		
1.....	4935.7		
1.....	4937.4		
6.....	4972.8 <i>a</i>	38.6 = 1×38.6	
2.....	5007.1		
4.....	5009.9		
6.....	5011.8 <i>a</i>	77.6 = 2×38.8	
1.....	5046.9		
8.....	5050.3 <i>a</i>	116.1 = 3×38.7	
1.....	5085.5		
1.....	5088.7		
8.....	5089.1 <i>a</i>	154.9 = 4×38.7	
1.....	5091.1		
2.....	5123.4 <i>b</i>		
8.....	5128.5 <i>a</i>	194.3 = 5×38.8	
6.....	5161.6 <i>b</i>		38.2 = 1×38.2
3.....	5164.2		
6.....	5167.7 <i>a</i>	233.5 = 6×38.9	
2.....	5192.6 <i>c</i>		
1.....	5193.8		
1.....	5198.2		
8.....	5200.0 <i>b</i>		76.6 = 2×38.3
2.....	5202.6		
8.....	5207.2 <i>a</i>	273 = 7×39	
1.....	5238.3 <i>b</i>		114.9 = 3×38.3
2.....	5241.2		
4.....	5245.9 <i>a</i>	311.7 = 8×38.9	
1.....	5267.4 <i>c</i>		
1.....	5274.3		
2.....	5277.6 <i>b</i>		154.2 = 4×38.5
2.....	5286.5 <i>a</i>	352.3 = 9×39.1	
1.....	5291.3		
1.....	5294.6		
1.....	5300.2		
2.....	5303.6 <i>c</i>		
1.....	5318.5 <i>b</i>		195.1 = 5×39.0
1.....	5321.3 <i>a</i>	387.1 = 10×38.7	
1.....	5331.8		
1.....	5336.6		

BARIUM EXCITATION—*Continued*

Intensity	Wave-Length	Series <i>a</i> . $k=38.8$	Series <i>b</i> . $k=38.4$
I.....	5339.5		
I.....	5341.1		
I.....	5354.3		
I.....	5425.3		
I.....	5443.3		

to these lines there are many others in the violet. There does not appear to be any series connected with them, but they have not the blurred appearance due to scattered light, and they have the same sharpness and intensity as the brightest fluorescent lines. It is therefore suspected that they form part of the complete resonance spectrum, and they have been included in the following table of the barium resonance spectrum, in which they are marked with an asterisk. The series which occur may be described as a more complicated version of the lead series. The lines which are apparently the first two members of the primary or *a* series have a spacing of only 37 Å. U. They have not been included in taking the general average for *k*. It is possible that the presence of the barium line λ 4900 may have had some influence on the spacing. The lines in the middle of the spectrum which have not been arranged in series are faint lines which occur as companions to the brighter lines, and a great number of lines at the end of the spectrum. The number of these faint unclassified lines is much greater than in the lead excitation. They seem to be fragments of a series which just appears for two or three members on either side of a principal series or even a strong secondary series and then disappears. Attention is directed to the two lines marked *c* in the table which form one such fragment. They are of interest in connection with the lithium excitation.

LITHIUM EXCITATION

The lithium arc stimulation is an important one, since we have four exciting lines: one in the violet λ 4603, a second in the green λ 4972, and two in the red λ 6104 and 6708. These lines are, however, so far apart that their resonance spectra do not overlap and can be studied separately. A photograph of the complete spectrum is shown on Plate XI, Fig. 5. The spectrum excited by the green line,

λ 4972, is an interesting one since its principal series almost coincides with the principal series of the barium line λ 4934. Comparing the wave-lengths in the two tables it will be seen that some are almost identical, and the average difference between corresponding members of a series is only 0.5 Å. U. But in the case of lithium, the principal

LITHIUM EXCITATION

Intensity	Wave-Length	Series a. $k=38.7$	Series b. $k=38.4$	Series c. $k=37.5$
4	4862.1 <i>a</i>	110.0 = 3 × 36.6		
4.....	4896.5 <i>a</i>	75.6 = 2 × 37.8		
10.....	4934.5 <i>a</i>	37.6 = 1 × 37.6		
8.....	4972.1 <i>a</i>			
1.....	4978.4			
1.....	5006.8			
2.....	5010.9 <i>a</i>	38.8 = 1 × 38.8		
1.....	5011.3			
8.....	5049.9 <i>a</i>	77.8 = 2 × 38.9		
1.....	5080.7			
1.....	5085.0			
8.....	5089.0 <i>a</i>	116.9 = 3 × 39		
1.....	5114.5 <i>c</i>			77.3 = 2 × 38.6
2.....	5118.7			
1.....	5118.5			
2.....	5124.0 <i>b</i>			
1.....	5124.4			
8.....	5128.0 <i>a</i>	155.9 = 4 × 39.0		
1.....	5129.5			
2.....	5152.8 <i>c</i>			39.0 = 1 × 39.0
1.....	5153.4			
1.....	5162.1			
4.....	5162.4 <i>b</i>		38.4 = 1 × 38.4	
4.....	5167.3 <i>a</i>	195.2 = 5 × 39.0		
1.....	5167.8			
2.....	5191.8 <i>c</i>			
2.....	5198.6 <i>b</i>			
2.....	5206.9 <i>a</i>			
4.....	5229.5 <i>c</i>			37.7 = 1 × 37.7
1.....	5237.7			
6.....	5266.7 <i>c</i>			74.9 = 2 × 37.4
6.....	5304.3 <i>c</i>			112.5 = 3 × 37.5

series soon disappears and its place is taken by the secondary series *c*, whose lines become stronger as we go up to the end of the spectrum. An inspection of the barium table reveals the existence of the two lines already mentioned which correspond to this lithium series. Likewise we find that the lithium spectrum has two lines which belong to the barium *b* series. It seems, therefore, to be fairly reasonable to conclude that we have the same vibrating system in the two cases, but

that the change in the frequency of the impressed oscillation has altered the distribution of intensity in the forced oscillations.

The disappearance of the principal series and the appearance of the secondary series can be best seen by referring to the chart (Plate X) on which the series are denoted by letters *a*, *b*, *c*, etc. The spacings on the chart should be studied with a pair of dividers.

It is worthy of note that the line $\lambda 4934$ in the resonance series one space below the exciting line (i. e., coinciding with the barium line) is stronger than the exciting line $\lambda 4972$. This is the only case in which this has been observed. It is moreover not the case in an earlier photograph taken with a small two-prism spectroscope, which is the one reproduced on Plate XI, Fig. 5.

The resonance spectrum excited by the $\lambda 4603$ line of lithium has not yet been obtained in a satisfactory condition for measurement. On the plate made with the 12-foot grating the series in the vicinity of the $\lambda 4603$ line (see Fig. 5) did not come on the plate at all, and the lines in the yellow-green (indicated by a $\sim$ in Fig. 5) and which owe their existence to the $\lambda 4603$ stimulation were too faint and hazy to permit satisfactory measurement. This work will have to be repeated.

MAGNESIUM EXCITATION

In the fluorescence excited by the magnesium arc we have the three lines of the green triplet acting together. These lines are so close together that it is not possible to obtain the excitation due to each separately. But it is quite easy to group the brightest lines in the spectrum in three principal series, *a*, *b*, *c*, one for each exciting line, as will be seen in the following table. Each line of the magnesium triplet excites a series of equally spaced lines, and these series taken together give a spectrum in which we find the triplet occurring at regular intervals—Plate XI, Fig. 10 (from an earlier photograph), and Fig. 11 (12-foot grating), on which only the strongest lines reproduce owing to the very narrow slit.

There does not seem to be any well-marked secondary series, though there seems to be what has been already called fragments of series associated with the series *c*. These have been indicated by the letters *d*, *e*, *f*, but it has not been considered worth while to tabulate their differences.

MAGNESIUM EXCITATION

Intensity	Wave-Length	Series a. $k=38.9$	Series b. $k=38.1$	Series c. $k=38.5$
4.	4842.3 <i>c</i>			341.5 = 9×37.9
4.	4865.8 <i>b</i>		307.1 = 8×38.4	
4.	4878.2 <i>c</i>			305.6 = 8×38.2
4.	4903.5 <i>b</i>		269.4 = 7×38.5	
4.	4916.9 <i>c</i>			266.9 = 7×38.2
2.	4931.4			
2.	4947. <i>f</i>			
2.	4953.9 <i>c</i>			229.9 = 6×38.3
2.	4966.4			
4.	4979.7 <i>b</i>		193.2 = 5×38.6	
4.	4984.5 <i>f</i>			
4.	4991.9 <i>c</i>			191.9 = 5×38.4
	5019.5 missing			
2.	5022.7 <i>f</i>			
4.	5030.2 <i>c</i>			153.6 = 4×38.4
2.	5034.1			
2.	5050. <i>a</i>	117.5 = 3×39		
2.	5055.4 <i>g</i>			
2.	5059.6 <i>b</i>		113.3 = 3×37.8	
2.	5088.9 <i>a</i>	78.6 = 2×39.2		
4.	5094.9 <i>g</i>			
4.	5097.3 <i>b</i>		75.6 = 2×37.8	
1.	5101.5 <i>d</i>			
6.	5106.6 <i>c</i>			77.2 = 2×38.6
1.	5110.8 <i>g</i>			
2.	5124.5			
2.	5128.3 <i>a</i>	39.2 = 1×39.2		
2.	5133.7 <i>g</i>			
6.	5135. <i>b</i>		37.9 = 1×37.9	
2.	5139.8			
2.	5142.4 <i>e</i>			
6.	5145.1 <i>c</i>			38.7 = 1×38.7
10.	5167.5 <i>a</i>			
10.	5172.9 <i>b</i>			
1.	5180.9 <i>e</i>			
10.	5183.8 <i>c</i>			
8.	5210.9 <i>b</i>		38. = 1×38	
2.	5220.4 <i>e</i>			
8.	5222.9 <i>c</i>			39.1 = 1×39.1
2.	5245. <i>a</i>	77.5 = 2×38.7		
2.	5249.2 <i>b</i>		76.3 = 2×38.1	
4.	5257.1 <i>d</i>			
4.	5262.3 <i>c</i>			78.5 = 2×39.2
1.	5298.2 <i>e</i>			
1.	5300.8 <i>c</i>			
1.	5305.7			117. = 3×39

COPPER EXCITATION

The resonance spectrum excited by the copper arc is shown on Plate XI, Fig. 9, in coincidence with the barium excitation and in Fig. 16 in coincidence with the magnetic rotation spectrum.

COPPER EXCITATION

Intensity	Wave-Length	Series <i>a.</i> $k=38$	Series <i>b.</i> $k=38.4$	Series <i>c.</i> $k=38.7$	Series d_1 Series d_2
I	4812.3				
I	4814.2				
I	4823.5				
I	4825.4				
I	4839.1 <i>a</i>				
I	4848.5				
I	4851.3				
I	4859.3				
I	4860.7				
I	4867.6				
2	4872.0 <i>c</i>			346.5 = 9 × 38.5	
2	4877.1 <i>a</i>	228.6 = 6 × 38.1	269.1 = 7 × 38.2		
2	4884.3 <i>b</i>				
I	4887.8				
I	4896.4				
I	4910.9 <i>c</i>			307.6 = 8 × 38.4	
I	4915.1 <i>a</i>	190.6 = 5 × 38.1			
4	4921.8 <i>b</i>		231.6 = 6 × 38.6		
4	4925.5				
I	4932.8				
I	4948.4 <i>c</i>			270.1 = 7 × 38.6	
4	4952.9 <i>a</i>	152.8 = 4 × 38.2			
2	4955.4				
I	4963.0 <i>b</i>		190.4 = 5 × 38.1		
I	4966.4				
I	4979.9				
I	4985.5 <i>c</i>			232.9 = 6 × 38.7	
4	4991.1 <i>a</i>	114.6 = 3 × 38.2			
2	4993.1				
I	4994.7				
2	4998.1 <i>b</i>		155.3 = 4 × 38.8		
6	5004.1				
I	5010.2				
I	5016.2				
I	5024.0 <i>c</i>			192.5 = 5 × 38.7	
2	5030.5 <i>a</i>	75.2 = 2 × 37.6			
2	5036.1				
6	5038.5 <i>b</i>		114.9 = 3 × 38.3		
I	5042.3				
I	5045.4				
6	5059.0				
I	5061.4 <i>c</i>			157.1 = 4 × 39.3	
6	5067.4 <i>a</i>	38.3 = 1 × 38.3			
2	5076.0 <i>b</i>		77.4 = 2 × 38.7		
I	5080.3				
2	5083.1				
2	5086.9 d_1				37.4 = 1 × 37.4
I	5091.7				
I	5101.2 <i>c</i>			117.3 = 3 × 39.1	
10	5105.7 <i>a</i>				
I	5112.				
6	5123.2				

COPPER EXCITATION—Continued

Intensity	Wave-Length	Series <i>a</i> , $k=38$	Series <i>b</i> , $k=38.4$	Series <i>c</i> , $k=38.7$	Series <i>d</i> ₁ Series <i>d</i> ₂
1	5124.3 <i>d</i> ₁	38.4 = 1 × 38.4		78.6 = 2 × 39.3	
1	5126.9				
2	5130.5 <i>d</i> ₂				
4	5139.9 <i>c</i>				
4	5144.1 <i>a</i>				
10	5153.4 <i>b</i>	76.1 = 2 × 38		39.2 = 1 × 39.2	38.7 = 1 × 38.7 38.0 = 1 × 38.0
2	5163.0 <i>d</i> ₁				
1	5168.5 <i>d</i> ₂				
4	5179.3 <i>c</i>				
4	5181.8 <i>a</i>				
4	5183.0		37.5 = 1 × 37.5		
4	5190.9 <i>b</i>				
8	5192.8				
4	5201.4 <i>d</i> ₁				
2	5206.8 <i>d</i> ₂				
2	5209.8			37.0 = 1 × 37.5	77.1 = 2 × 38.5 76.3 = 2 × 38.1
10	5218.5 <i>c</i>				
1	5230.9 <i>b</i>				
1	5243.8				
1	5247.5 <i>d</i> ₂				
6	5256.2 <i>c</i>		116 = 3 × 38.7	117 = 3 × 39.0	
2	5266.2				
2	5269.4 <i>b</i>				
1	5273.0				
4	5278.5 <i>d</i> ₁				
1	5281.3			74.5 = 2 × 37.2	154.2 = 4 × 38.5 154.0 = 4 × 38.4
1	5284.3 <i>d</i> ₂				
4	5293.0 <i>c</i>				
1	5302.6				
1	5307.3 <i>b</i>				
1	5313.2	153.9 = 4 × 38.5			191.7 = 5 × 38.3
1	5322.2 <i>d</i> ₂				
1	5326.3				
1	5344.2 <i>b</i>				
1	5352.0				
1	5356.4 <i>d</i> ₁	190.8 = 5 × 38.2			232.1 = 6 × 38.5 229.9 = 6 × 38.3
1	5360.4 <i>d</i> ₂				
1	5367.7				
1	5380.8 <i>b</i>				
1	5390.5 <i>d</i> ₁				
1	5397.5 <i>d</i> ₂	227.4 = 6 × 37.9			266.2 = 7 × 38.0 267.0 = 7 × 38.2
1	5410.6				
1	5415.5				
1	5431.7				
1	5449.8				
1	5463.4				
1	5470.9				
1	5495.3				
1	5508.7				
1	5529.1				
1	5538.7				
1	5556.5				

It has not been possible to photograph separately the fluorescence produced by each of the three green lines in the copper arc, as even the fluorescence excited by the three lines together was very faint and required a twenty-hour exposure. But, as in the case of magnesium, there was no difficulty picking out the three principal series, *a*, *b*, *c*, one for each exciting line. The arrangement is not very satisfactory, since the spacing is not very constant, and a great many of the strong lines in the spectrum are left outstanding. In addition, a series of doublets d_1 d_2 has been found which may be the series previously observed to be excited by the shortest copper line, λ 5105.7. One or other member of the doublet is lacking in places, so the tables of differences have been calculated from the first complete doublet. This series of doublets is only a secondary series since it does not contain the exciting line as a member. It will be remarked that the wave-length of the exciting line is a mean between the wave-lengths of two members of the series *d*, which may possibly have some significance.

ZINC AND BISMUTH EXCITATIONS

The bismuth arc excites a very brilliant fluorescence, which is entirely due to the blue line λ 4722.7. The resonance spectrum photographed with the 12-foot grating is reproduced on Plate XI, Fig. 6. The fainter lines do not appear in the reproduction and a better idea of the complete spectrum can be had from the chart. Many lines also, which appear single on the print, are in reality close doublets.

In addition to the strong series lines on either side of the exciting line there is a multitude of lines in the yellow-green region. This portion of the spectrum is shown at the bottom of the chart on a scale which is four times larger than that of the upper portion. It resembles closely the resonance spectrum excited by the zinc line λ 4810. The spectrum stimulated by the three blue zinc lines is shown on Plate XI, Fig. 7, and also on the chart. The yellow-green region is of great interest. The two photographs (Figs. 6 and 7) should be compared with the photograph of the fluorescence excited by white light, Fig. 1. The iron lines make it easy to locate the region in which the zinc and bismuth resonance spectra fall. The almost continuous banded spectrum excited by white light, under the micro-

scope is seen to be made up of a multitude of fine lines, ten or more in each one of the flutings. Monochromatic excitation causes the appearance of only a very small percentage of these lines, but they are arranged in a very definite order, as the photographs show. In the bismuth excitation we find a triplet occurring four times at regular intervals, groups of four or five lines being found midway between the triplets. On the chart will be found a drawing of a small portion of the white-light fluorescence spectrum, between the resonance spectra excited by bismuth and zinc. This gives a very good idea of the way in which it is going to be possible to analyze this complicated band spectrum, by a further and more complete study of the resonance spectra.

The wave-lengths of the lines in the bismuth resonance spectrum are given in the following table:

BISMUTH EXCITATION

Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length
2.....	4655.7	6.....	5359.7	8.....	5441.4
2.....	4657.6	1.....	5371.6	7.....	5442.4
6.....	4688.9	1.....	5373.4	8.....	5446.0
6.....	4690.0	6.....	5374.3	6.....	5447.4
4.....	4698.5	6.....	5378.0	6.....	5456.5
1.....	4719.9	4.....	5378.4	4.....	5457.6
10.....	4722.7	6.....	5379.1	6.....	5459.1
2.....	4723.0	2.....	5388.2	4.....	5462.0
1.....	4726.7	5.....	5391.4	4.....	5463.2
6.....	4756.4	5.....	5392.8	2.....	5469.1
6.....	4757.3	1.....	5394.0	6.....	5469.8
2.....	4761.0	1.....	5394.9	4.....	5470.3
2.....	4764.5	6.....	5407.3	6.....	5472.5
4.....	4790.6	6.....	5408.3	6.....	5473.1
4.....	4792.8	2.....	5410.1	6.....	5474.4
1.....	5191.0	6.....	5412.1	6.....	5480.2
2.....	5250.3	6.....	5413.4	6.....	5480.8
1.....	5251.0	4.....	5423.9	6.....	5489.0
2.....	5274.8	3.....	5425.9	6.....	5490.2
7.....	5299.8	8.....	5426.8	6.....	5491.9
2.....	5334.3	2.....	5427.3	6.....	5501.2
10.....	5337.7	2.....	5428.9	6.....	5504.8
1.....	5341.1	2.....	5430.1	2.....	5520.5
2.....	5344.4	2.....	5431.8	2.....	5521.3
2.....	5356.6	1.....	5436.7	4.....	5531.4
2.....	5358.1	1.....	5438.3	8.....	5552.6

A table of the wave-lengths of the lines excited by zinc will be found in a previous paper.¹

¹ *Physikalische Zeitschrift*, 9, 450-461, 1908.

The plate reproduced (Fig. 7) will have to be remeasured before a revised table can be published, as some errors have been detected in revising the work.

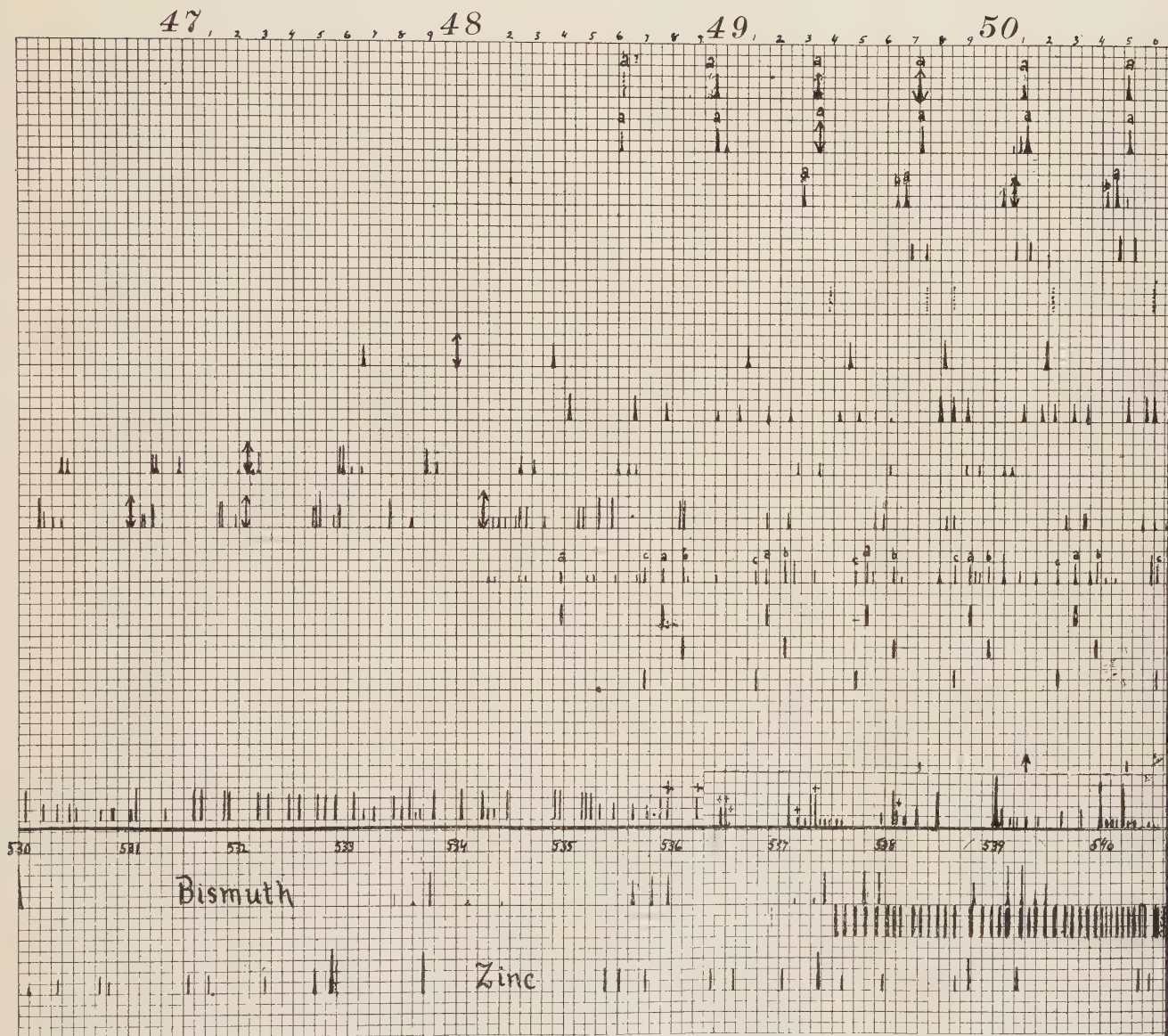
The close doublets, spaced off at equal intervals and marked x on the chart, which appear in the region λ 5100–5300 of the resonance spectrum excited by the zinc arc, are worthy of notice.

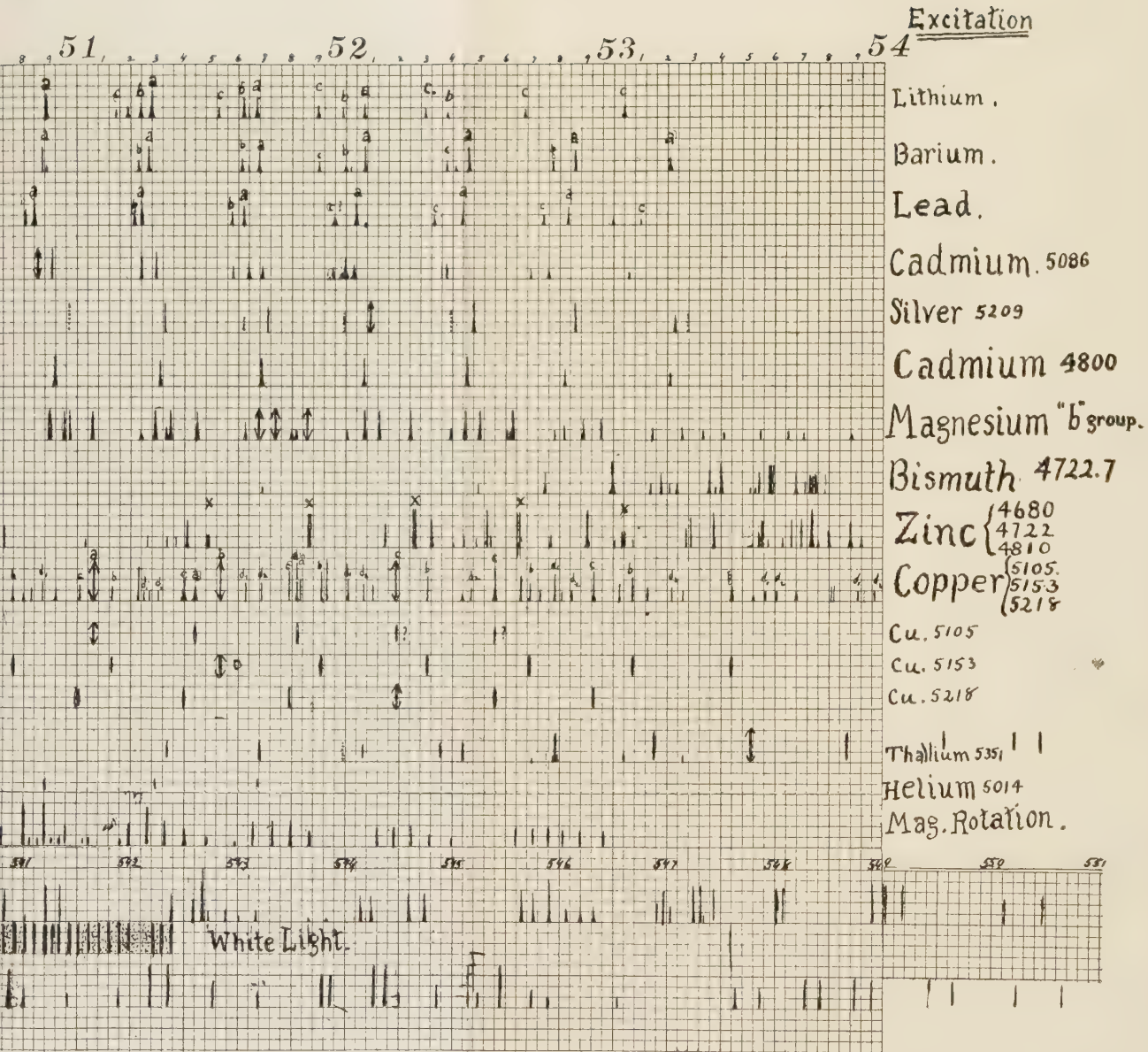
As will be seen from the chart the series lines in the blue are close doublets. This may be due to the fact that we are exciting the vapor with a double line (that is, a self-reversed line). The photographs of the absorption spectrum, made by Mr. Clinkscales with the 21-foot grating in the second order, show that the absorption lines are often not more than one-tenth of an Ångström unit apart, consequently a self-reversed line might easily excite two different frequencies. This point requires further investigation.

BLUE-GREEN MAGNETIC ROTATION SPECTRUM

This is shown in coincidence with the white-light fluorescence spectrum on Plate XI, Fig. 2, and in coincidence with the resonance spectrum excited by the zinc arc in Fig. 17. On the new plates 128 lines are shown as compared with 64 lines measured in the previous work. The general result of the new measurements is to emphasize and extend many of the relations which were observed in the first work on the subject. Looking down the list, groups of strong lines will be observed to recur at regular intervals toward the end of the spectrum. Some of these lines were found to be almost coincident with some of the series in the resonance spectra. By comparing these with the magnetic rotation lines, Wood found it possible to arrange many of them into five series, which are numbered from 1 to 5 in the table given on p. 360.

The lines in the blue below λ 4900 become more numerous and irregular in their arrangement; but the series have not been extended into this region as might be done, since we have no corresponding fluorescent series which extend so far. This will be seen by consulting the chart (Plate X) accompanying this paper. As long as we have such a series to guide us in selection we may be sure that the grouping has a physical significance; but when this fails, any further extension of the series can be regarded only as a formal classification.





The most interesting problem in connection with the magnetic rotation is the determination of the direction of rotation of the light in these lines. An attempt was made to study the direction of rotation by means of the Fresnel quartz wedges which gave such beautiful results in the magnetic rotation spectrum in the red, but there was little or no trace of the bright needles of light shooting up or down into the dark interference band (see Plate XI, Fig. 12, for a photograph of this phenomenon in the red). Their failure to appear in the green is due to the smaller angular rotation of the plane of polarization. The problem was finally solved in a different manner for the green spectrum. These wave-lengths in the plane-polarized light passing through sodium vapor along the lines of force in a magnetic field are rotated through a few degrees so that they can pass through a nicol set to extinction for the rest of this region of the spectrum. A small rotation of the nicol in either direction will now brighten up the whole field. In one direction some of the bright lines will still be seen, though less distinctly against the bright background of the rest of the spectrum. Careful observation, however, will show that if the nicol is rotated about four degrees in the opposite direction, these lines disappear. These lines have therefore been rotated about four degrees in this direction by passing through the sodium vapor in the magnetic field. It was observed that the rotation in the brightest lines belonging to the magnetic series was in the same direction as that due to the D lines. The rotation of these lines is therefore presumably due to negative electrons and they have been marked with the negative sign in the third column of the table.

To extend this process to the whole spectrum it was only necessary to take two photographs of the spectrum on the same plate, one in which the nicol was rotated four degrees to the left, and the other in which it was rotated four degrees to the right. These two photographs were totally different, as the bright lines of one were absent in the other. By careful comparison of this plate with the magnetic rotation spectrum, the direction of rotation of all the strong lines could be ascertained at leisure.

All those lines which appeared on the same photograph as the magnetic rotation series and were not visible on the other were therefore rotated in the same direction and have been marked in the

Intensity	Series	Sign of Rotation	Green Magnetic Rotation Spectrum	Intensity	Series	Sign of Rotation	Green Magnetic Rotation Spectrum
2.....			4609	4.....	3		4865.5
2.....			4611.3	4.....		—	4871.5
2.....			4615.8	2.....			4875.1
2.....			4628	4.....		+	4878.2
2.....			4630.6	4.....		+	4889.4
2.....			4634.3	6.....			4892.9
2.....			4636.7	6.....	2?	—	4894.7
2.....			4641.9	6.....		+	4897.9
8.....			4648.9	4.....		+	4899.8
2.....			4653.8	4.....		+	4900.8
2.....			4658.6	6.....	3		4903.3
2.....			4661.2	6.....	4	—	4912.3
2.....			4670.4	10.....	1		4924.4
2.....			4674	2.....		+	4927.3
2.....			4675	10.....	2	—	4932.6
2.....			4681.2	8.....		+	4933.8
2.....			4682.6	2.....			4937.9
10.....		—	4693.7	2.....	3?		4941.6
4.....			4694.6	4.....	5?		4958.5
10.....		—	4703.9	10.....	1	—	4962.5
10.....			4706.5	4.....		+	4964
10.....			4715.4	4.....			4966.8
10.....			4716.9	8.....	2		4971.7
10.....		—	4727.5	10.....	3	—	4979
10.....			4731.4	2.....	4		4985.2
10.....		—	4738.5	10.....	1	—	5001.6
10.....		—	4741.8	6.....	2		5003
10.....		—	4749.3	4.....			5000.3
10.....			4752.1	4.....			5007.2
10.....			4756.6	4.....			5008.2
10.....			4762.7	4.....			5009.4
10.....			4766.7	4.....			5012.7
4.....		—	4769.8	4.....	3		5017.5
4.....			4777.1	5.....	4		5025.1
4.....			4780.4	5.....	5		5033.3
10.....		—	4782.8	9.....	1	—	5040.2
2.....		—	4784.9	4.....			5044.2
1.....			4786.8	4.....			5045.7
2.....			4787.5	8.....	2		5048.3
1.....			4789.5	4.....			5049.4
10.....		—	4792.4	4.....		—	5052.6
10.....		—	4802.2	4.....	3		5058.4
10.....			4809.9	8.....	5		5071.8
4.....		—	4812.2	8.....	1	—	5079.9
4.....			4814.5	8.....	2	—	5087.4
10.....			4819	8.....	3		5094.8
10.....			4837.3	2.....			5097.5
4.....		—	4839	4.....			5102.3
4.....		—	4846.8	2.....			5115.8
4.....			4848.4	8.....	1	—	5119.1
4.....			4850	8.....	2	—	5126.3
4.....			4852.7	8.....	3	—	5133.3
4.....			4858.3	8.....	4		5140.8

Intensity	Series	Sign of Rotation	Green Magnetic Rotation Spectrum	Intensity	Series	Sign of Rotation	Green Magnetic Rotation Spectrum
8.....			5148.8	1.....			5228.3
6.....			5159.1	1.....	1?		5232.2
8.....	2	—	5165.8	4.....			5238.9
8.....	3	—	5173.1	2.....			5243
8.....	4		5179.6	6.....	5?		5263.8
8.....	5		5186.5	6.....	1?		5270.3
8.....			5192.3	6.....	2?		5276.6
8.....	3		5212.1	6.....	3?		5282.6
8.....	4		5218.3	6.....	4?		5288.6
8.....	5		5225.4	6.....			5298.9

table in the same way. There were some lines which appeared only on the photograph in which the series were absent, and so were rotated in the opposite direction. These have been provisionally assumed to be due to positive electrons and are marked with the positive sign in the table.

These lines are nearly all below $\lambda 4900$, and though a formal grouping is possible, it has not been considered worth while to make any assignment of them into series until it has been ascertained if there are any fluorescent lines corresponding to them.

The magnetic rotation lines are shown on the chart.

WHITE-LIGHT FLUORESCENCE

There is a very interesting connection between the white-light fluorescence and the magnetic rotation. In the photograph obtained with the grating, the fluorescence in the green extends from $\lambda 4700$ — $\lambda 5500$, its brightest region being from $\lambda 5000$ — $\lambda 5500$. Below this the spectrum is weak and contains a great number of fine lines among which there is a very irregular distribution of intensity. Beyond $\lambda 5000$ we have a well-defined system of bands. On examining them with an eyepiece these bands are found to consist of a great number of fine lines (see Fig. 4 at point indicated by arrow). On the violet edge of each band there is a narrow region about two Ångström units wide, in which there is no fluorescence at all, or it is a minimum. If the photograph of the magnetic rotation spectra be superposed, the lines will be found to coincide with these dark spaces. It will be seen from the table given below that the magnetic rotation

lines are usually about 1 Å. U. shorter so that they are always on the violet side of the bright lines in the fluorescence. The measurements of the wave-lengths of the heads of the bands can be considered only approximate, but they serve for the purposes of comparison. A complete table of these is given first and then a table of those lines in the two spectra which correspond.

On account of this correspondence between the two spectra it is possible to arrange the fluorescent bands in series which are in step

WHITE-LIGHT FLUORESCENCE

Wave-Length	Wave-Length	Wave-Length	Wave-Length	Wave-Length	Wave-Length	Wave-Length
5026.1	5126.5	5203.4	5277.1	5323	5392.1	5453.3
5034.1	5133.2	5210.1	5283.2	5338.7	5397.4	5458.2
5041	5141.2	5216.6	5289.7	5345	5417.2	5476
5049	5148.3	5232.5	5296	5351.2	5422.2	5481
5050.2	5159.7	5238.3	5302.9	5364.2	5427.2	5485.9
5072.1	5166	5245.6	5308.6	5369.4	5431.3	5490.5
5081	5173.1	5249.1	5314.8	5375.4	5436.8	5496
5088.4	5180.1	5254.6	5320.8	5381	5443.2	5500.4
5095.4	5186.9	5264.1	5326.8	5386.4	5448.2	5505.3
5119.6	5193.8	5270.6				

WHITE-LIGHT FLUORESCENCE AND MAGNETIC ROTATION SERIES

Series	White-Light Fluorescence	Magnetic Rotation	Series	White-Light Fluorescence	Magnetic Rotation
4.....	5026.1	5025.1	3.....	5173.1	5172.9
5.....	5034.1	5033.3	4.....	5180.1	5179.6
1.....	5041	5040.2	5.....	5186.9	5186.5
2.....	5050.2	5048.3	1.....	5193.8	5192.3
5.....	5072.1	5071.8	1?.....	5232.5	5232.2
1.....	5081	5079.9	2?.....	5238.3	5238.9
2.....	5088.4	5087.4	3?.....	5245.6	5243
3.....	5095.4	5094.8	4?.....	5249.1	
1.....	5119.6	5119.1	5?.....	5264.1	5263.8
2.....	5126.5	5126.3	1?.....	5270.6	5270.3
3.....	5133.2	5133.3	2?.....	5277.1	5276.6
4.....	5141.1	5140.8	3?.....	5283.2	5282.6
5.....	5148.3	5148	4?.....	5289.7	5288.6
1.....	5159.7	5159.1	5?.....	5296.0	
2.....	5166	5165.8			

with the magnetic rotation series and also with the resonance series. This is illustrated by the chart. The series apparently becomes disorganized after the termination of the magnetic rotation and cannot be carried farther. Beyond this new bands appear and though

there seems to be some regular arrangement it is different in kind. It must be studied in conjunction with the resonance spectra in the same region excited by the zinc and bismuth arcs. As a result of the regular grouping between λ 4900 and λ 5300 the white-light fluorescence can be almost entirely represented by a system of five bands which recur at regular intervals along the spectrum. According to the scheme developed at the close of the paper each of these bands is due to one vibrating system and the whole five bands are interconnected. The great regularity found in the resonance spectra in this region falls in with this scheme.

THE RESONANCE AND MAGNETIC ROTATION SPECTRA IN THE ORANGE AND RED REGION

The red region of the fluorescence spectrum excited by white light appears nearly continuous. Occasionally faint traces of bands can be seen if the vapor density is just right and the illumination is very intense.

The magnetic rotation bright-line spectrum is, however, much brighter than in the blue-green region and quite as discontinuous. A portion of it (about $\frac{1}{2}$) is shown on Plate XI, Fig. 15. On this plate the iron comparison spectrum below is quite faint. Immediately above (Fig. 12) will be seen one of the plates from which the direction of rotation of each line was determined by the method described in an earlier paper. The dark band running horizontally through the center of the spectrum is caused by the failure of the nicol prism to transmit the horizontally polarized light in the region. Immediately above and below this line, the light in the spectrum is polarized vertically and is consequently passed by the nicol. This "distribution of polarization" is accomplished by the double Fresnel wedge of dextro- and laevo-rotatory quartz. The absorption lines of the sodium vapor are beautifully shown. When the vapor is magnetized the wave-lengths which are rotated by the vapor are shown by needles of light which shoot up or down into the horizontal dark line according to the direction of the rotation.

The wave-lengths of the lines in the red magnetic rotation spectrum are given in the following table. There are over 340 in all, or two and a half times as many as in the green-blue spectrum.

RED MAGNETIC ROTATION SPECTRUM

Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length
2.....	5943.8	2.....	6150.0	4.....	6315.4
2.....	5945.0	1.....	6159.1	2.....	6317.1
2.....	5945.2	8.....	6163.1	2.....	6318.4
2.....	5958.1	2.....	6164.6	6.....	6320.6
3.....	5963.1	4.....	6165.9	2.....	6321.7
3.....	5966.8	4.....	6167.5	8.....	6323.8
3.....	5970.0	4.....	6170.1	8.....	6324.2
3.....	5974.0	6.....	6171.8	8.....	6325.5
3.....	5975.5	2.....	6172.9	2.....	6327.1
4.....	5995.4	8.....	6179.3	6.....	6334.5
2.....	5997.5	6.....	6181.4	2.....	6335.5
4.....	5998.9	2.....	6183.1	2.....	6338.9
2.....	6005.3	8.....	6184.2	2.....	6341.9
2.....	6007.0	1.....	6191.7	2.....	6344.3
4.....	6007.6	4.....	6196.8	4.....	6347.0
4.....	6012.9	8.....	6197.4	4.....	6351.2
4.....	6019.0	6.....	6198.1	4.....	6351.7
4.....	6020.0	6.....	6199.1	2.....	6353.9
4.....	6022.8	2.....	6204.6	2.....	6356.2
4.....	6024.2	2.....	6206.4	4.....	6358.6
4.....	6027.3	6.....	6210.4	2.....	6360.3
2.....	6029.0	4.....	6214.2	4.....	6364.8
4.....	6029.8	8.....	6215.6	6.....	6366.8
2.....	6030.7	6.....	6218.5	4.....	6368.8
4.....	6031.6	2.....	6221.6	2.....	6371.7
1.....	6037.2	2.....	6222.4	10.....	6373.5
1.....	6045.7	2.....	6225.7	4.....	6374.4
1.....	6049.5	4.....	6227.2	4.....	6376.2
1.....	6053.6	6.....	6229.6	6.....	6378.2
1.....	6062.8	8.....	6230.9	8.....	6379.3
6.....	6063.4	6.....	6236.4	2.....	6384.2
4.....	6069.3	6.....	6239.9	8.....	6385.9
2.....	6070.3	2.....	6251.3	8.....	6386.6
6.....	6071.4	6.....	6253.2	4.....	6388.5
4.....	6075.9	4.....	6255.2	8.....	6400.2
4.....	6076.6	8.....	6256.1	1.....	6402.3
2.....	6078.9	1.....	6257.4	4.....	6406.5
2.....	6080.5	4.....	6259.5	6.....	6407.0
1.....	6084.8	6.....	6259.6	2.....	6412.7
6.....	6086.3	8.....	6262.6	10.....	6420.1
2.....	6087.8	2.....	6266.5	4.....	6420.8
2.....	6090.9	4.....	6270.8	1.....	6422.1
4.....	6092.5	8.....	6273.2	4.....	6422.9
6.....	6107.6	2.....	6276.0	2.....	6424.0
8.....	6109.1	4.....	6276.9	10.....	6427.2
6.....	6112.7	4.....	6279.0	4.....	6429.3
6.....	6113.8	4.....	6285.3	10.....	6434.9
6.....	6120.8	8.....	6288.1	2.....	6437.8
8.....	6126.0	4.....	6290.3	4.....	6438.5
1.....	6133.5	7.....	6301.7	4.....	6440.3
1.....	6134.2	1.....	6308.4	4.....	6442.5
7.....	6139.2	2.....	6309.7	1.....	6444.0
6.....	6141.1	2.....	6312.1	8.....	6445.9
4.....	6143.6	8.....	6313.6	10.....	6449.8
4.....	6147.5	6.....	6314.4	4.....	6450.5

RED MAGNETIC ROTATION SPECTRUM—*Continued*

Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length
4.....	6451.3	2.....	6596.3	4.....	6810.8
2.....	6452.1	4.....	6600.9	4.....	6811.8
4.....	6458.1	8.....	6610.3	4.....	6815.2
2.....	6459.3	4.....	6613.4	2.....	6817.2
4.....	6462.8	2.....	6616.5	2.....	6818.3
2.....	6468.7	2.....	6617.7	2.....	6823.9
4.....	6470.5	2.....	6618.7	4.....	6833.0
2.....	6470.9	1.....	6621.5	4.....	6840.0
2.....	6472.1	2.....	6622.9	1.....	6864.7
4.....	6477.3	8.....	6624.2	2.....	6866.7
4.....	6478.0	6.....	6625.2	2.....	6869.8
4.....	6479.2	4.....	6626.2	1.....	6871.2
4.....	6480.0	1.....	6632.1	1.....	6872.6
4.....	6481.5	1.....	6635.4	8.....	6875.8
8.....	6481.8	1.....	6636.5	1.....	6877.4
8.....	6482.7	1.....	6641.0	1.....	6878.7
4.....	6483.6	6.....	6646.6	1.....	6880.9
4.....	6484.4	1.....	6657.5	1.....	6882.0
2.....	6485.4	4.....	6663.4	8.....	6885.8
4.....	6486.7	4.....	6664.4	4.....	6887.0
4.....	6487.7	1.....	6666.6	4.....	6889.4
6.....	6487.9	4.....	6668.2	4.....	6890.5
8.....	6490.1	1.....	6674.2	2.....	6904.1
8.....	6490.9	4.....	6675.7	2.....	6905.1
4.....	6494.8	6.....	6677.3	1.....	6933.5
2.....	6493.3	6.....	6678.9	1.....	6935.3
6.....	6502.4	2.....	6684.1	1.....	6936.9
4.....	6503.0	2.....	6685.8	1.....	6938.5
4.....	6504.6	4.....	6690.2	2.....	6941.1
2.....	6505.7	8.....	6692.9	2.....	6943.7
4.....	6510.1	1.....	6698.2	2.....	6945.2
2.....	6513.3	2.....	6704.6	6.....	6946.7
6.....	6515.0	1.....	6711.2	4.....	6948.1
6.....	6515.8	1.....	6714.3	4.....	6949.6
2.....	6516.9	1.....	6715.2	2.....	6952.9
1.....	6524.7	1.....	6727.0	2.....	6956.8
4.....	6532.4	2.....	6730.5	4.....	6958.1
2.....	6538.6	4.....	6734.4	8.....	6959.6
2.....	6544.1	4.....	6737.9	4.....	6961.0
10.....	6548.4	4.....	6739.1	4.....	6962.5
4.....	6549.9	6.....	6741.4	2.....	6964.2
4.....	6553.4	6.....	6746.7	2.....	6965.5
1.....	6554.6	2.....	6750.9	4.....	7008.5
4.....	6555.5	1.....	6754.1	4.....	7009.7
8.....	6557.1	1.....	6757.9	2.....	7016.1
8.....	6557.4	6.....	6761.9	4.....	7018.9
2.....	6558.4	6.....	6763.0	4.....	7020.0
1.....	6560.3	4.....	6767.1	8.....	7021.6
1.....	6561.5	2.....	6780.5	4.....	7022.6
4.....	6565.3	1.....	6793.8	4.....	7024.1
2.....	6567.4	4.....	6796.1	4.....	7028.2
2.....	6570.9	6.....	6803.5	4.....	7029.2
2.....	6573.6	6.....	6805.8	1.....	7031.6
3.....	6576.9	6.....	6806.7	2.....	7033.0
8.....	6580.3	4.....	6810.1	8.....	7034.7

RED MAGNETIC ROTATION SPECTRUM—*Continued*

Intensity	Wave-Length	Intensity	Wave-Length	Intensity	Wave-Length
4.....	7036.2	4.....	7098.8	2.....	7111.9
4.....	7037.8	4.....	7103.8	2.....	7113.8
2.....	7095.8	2.....	7109.1	2.....	7115.3
4.....	7097.3	4.....	7110.5		

Following this table is a classification of the lines according to the direction of rotation. The amounts of rotation, i. e., the distances to which the needle of light penetrates, is roughly indicated by numerals.

NEGATIVE MAGNETIC ROTATION LINES (λ 6000– λ 7000)

Intensity	Rotation	Wave-Length	Intensity	Rotation	Wave-Length	Intensity	Rotation	Wave-Length
2	4	5997.5	8	2	6262.8	2	6	6468.7
4	4	6019.0	4	2	6270.8	4	6	6477.3
4	2	6027.3	8	6	6273.2	4	7	6478.0
2	2	6030.7	2	6	6276.0	4	7	6479.2
1	4	6037.2	4	4	6279.0	4	8	6480.0
1	2	6045.7	8	2	6288.1	4	8	6481.5
6	2	6063.4	7	4	6301.7	8	10	6481.8
6	6	6071.4	8	10	6313.6	8	8	6482.7
4	8	6075.9	6	8	6314.4	8	10	6502.4
2	4	6084.8	2	6	6318.4	6	8	6503.0
1	1	6085.5	2	4	6335.5	4	4	6510.1
4	4	6092.5	2	4	6341.9	10	10	6548.4
6	4	6107.6	2	4	6344.3	1	8	6561.5
8	8	6126.0	6	4	6366.8	2	4	6573.6
6	4	6141.1	4	4	6368.8	8	10	6610.3
4	2	6147.5	2	4	6371.7	4	4	6626.2
2	2	6150.0	10	10	6373.5	4	8	6663.4
4	4	6167.5	6	4	6378.2	6	10	6678.9
4	4	6170.1	4	1	6388.5	2	6	6685.0
2	4	6172.9	8	10	6400.2	2	6	6698.2
8	4	6179.3	4	10	6406.5	4	6	6734.4
6	4	6181.4	6	10	6407.0	6	10	6746.7
8	10	6184.2	10	10	6420.1	2	2	6750.9
2	2	6204.6	4	8	6429.3	6	8	6803.5
6	2	6210.4	10	10	6434.9	6	8	6806.7
6	6	6218.5	2	4	6437.8	4	8	6889.4
8	8	6230.9	8	4	6445.9	4	8	6890.5
6	6	6236.4	4	8	6450.5	4	8	6949.6
6	4	6239.9	4	10	6451.3	4	2	7018.9
4	4	6253.2	4	6	6462.8	8	2	7021.6
8	4	6256.1						

POSITIVE MAGNETIC ROTATION LINES (λ 6000- λ 7200)

Intensity	Rotation	Wave-Length	Intensity	Rotation	Wave-Length
8	4	6109.1	4	4	6532.4
8	4	6126.0	8	10	6551.1
7	8	6139.2	8	10	6557.4
6	8	6199.1	8	6	6580.3
8	8	6215.6	4	10	6613.4
6	6	6259.6	8	10	6624.2
4	6	6315.4	4	4	6664.4
8	10	6323.8	6	10	6677.3
8	10	6324.2	8	10	6692.9
8	10	6325.5	4	4	6737.9
4	4	6351.2	6	10	6761.9
4	4	6358.6	6	4	6763.0
8	6	6379.3	6	4	6806.7
8	10	6385.9	4	4	6810.1
8	10	6386.6	4	4	6810.8
4	6	6388.5	4	8	6840.0
6	6	6407.0	8	4	6875.8
4	6	6422.9	8	6	6885.8
10	10	6427.2	4	6	6887.0
4	4	6442.5	4	4	6946.7
10	10	6449.8	4	10	6959.6
2	4	6470.9	8	4	7008.5
4	8	6486.7	8	6	7021.6
8	10	6490.1	8	4	7034.7
8	10	6490.9	4	6	7047.8
6	8	6502.4	4	6	7111.9
6	6	6515.0	2	6	7115.3
6	6	6515.8			

LITHIUM EXCITATION IN THE RED

The red resonance spectrum excited by the lithium lines λ 6104 and 6708 has been photographed only with a small two-prism spectrograph (Fig. 5). The wave-lengths can be considered accurate only to within 2 or 3 Å. U. The series-difference k is nearly twice as large as in the green-blue region; $k=54$ and $k=63$ for the two series.

By comparing the magnetic rotation spectrum with the lithium resonance spectrum, two series have been found in the table of positively rotated lines with spacings of 63 and 67. These series include all of the strong lines. The negative lines do not yield themselves so readily to arrangement in series and nothing has yet been done with them.

The wave-lengths of the red resonance lines, and the table of the series in the positive magnetic rotation spectrum follow.

LITHIUM EXCITATION (λ 5800-7100)

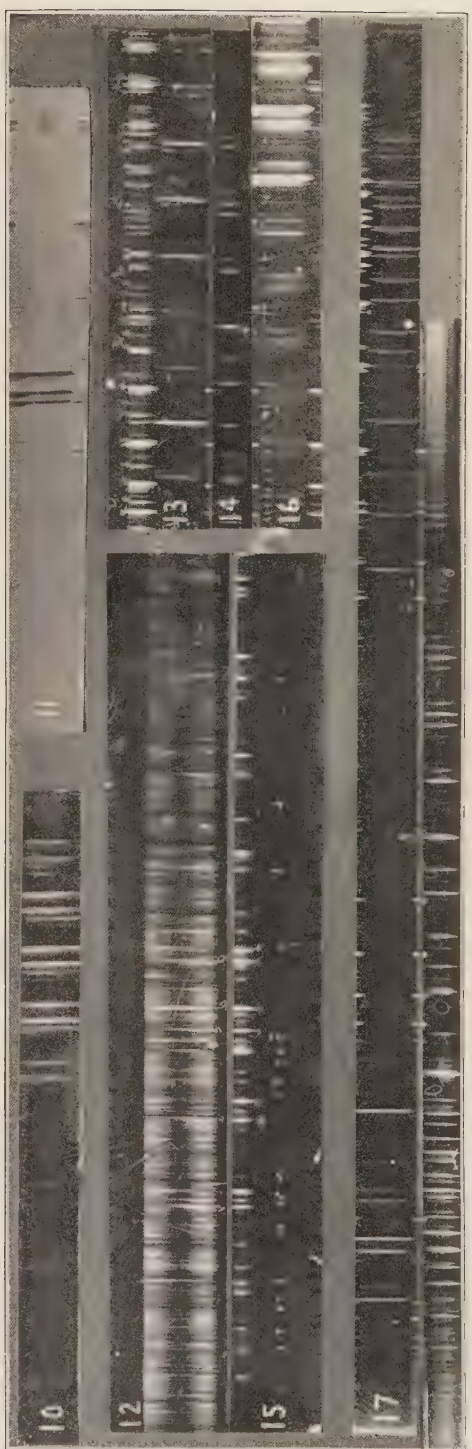
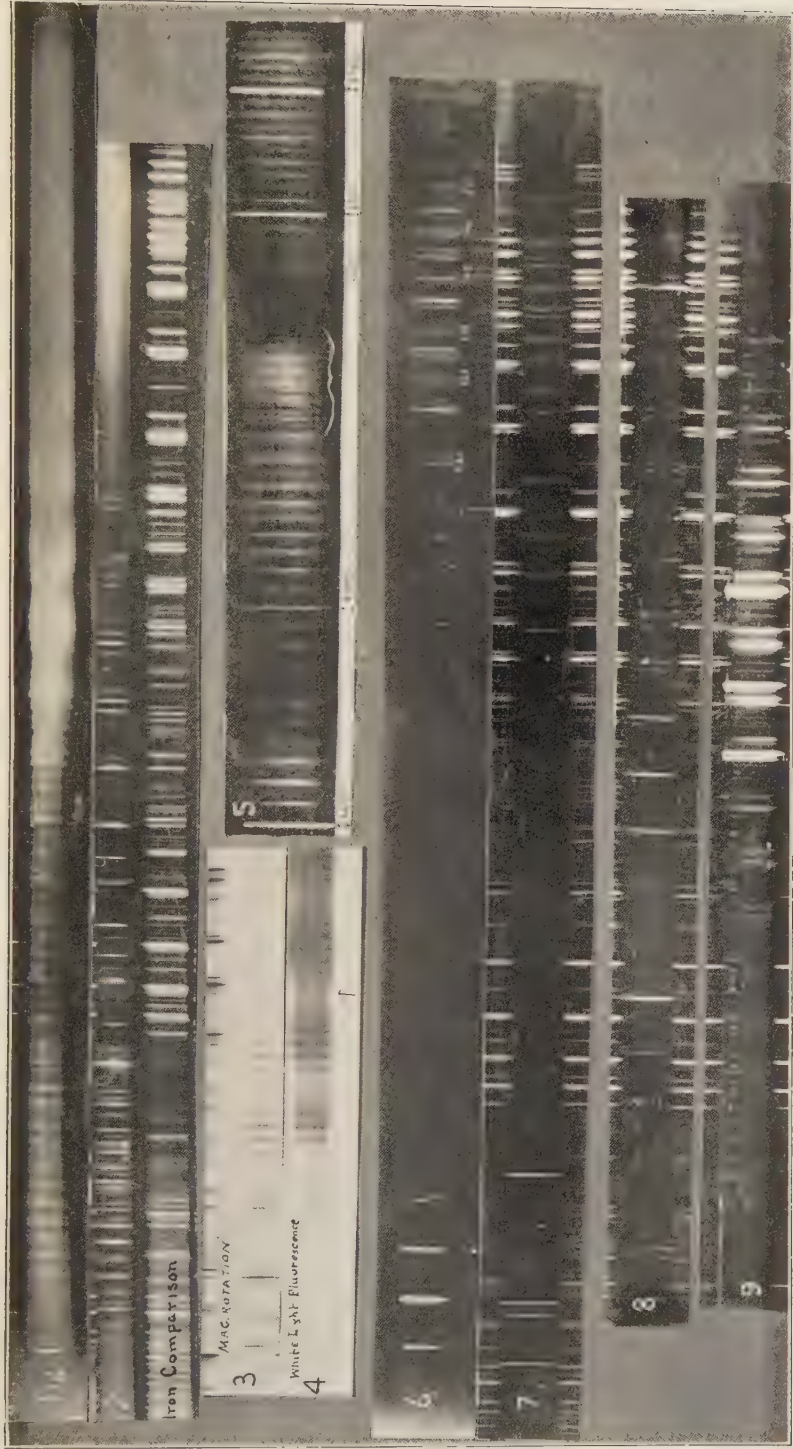
Wave-Length	Series a. $k=54$
	Series b. $k=63$
5896 a	206 = 4×52
5942 a	160 = 3×53
5998 a	104 = 2×52
6047 a	55 = 1×55
6102	
6158 a	56 = 1×56
6218 a	116 = 2×58
6277 b	431 = 7×62
6338 b	370 = 6×62
6396 b	312 = 5×62
6461 b	247 = 4×62
6510 b	180 = 3×63
6580 b	128 = 2×64
6643 b	65 = 1×65
6708	
6772 b	64 = 1×64
6834 b	126 = 2×63
6898 b	190 = 3×63
6965 b	257 = 4×64
7015 b	307 = 5×62
7074 b	366 = 6×61

SERIES IN THE POSITIVE MAGNETIC ROTATION (λ 6000- λ 7200)

Intensity	Rotation	Wave-Length	Series Differences
7	8	6139.2	310.6 = 5×62.1
6	8	6199.1	250.7 = 4×62.7
6	6	6259.6	190.2 = 3×63.4
8	10	6323.8	126.6 = 2×63.3
8	10	6324.5	125.6 = 2×62.8
8	10	6325.5	124.3 = 2×62.1
10	10	6449.8	
6	6	6515.0	65.2 = 1×65.2
6	6	6515.8	66.0 = 1×66.0
8	6	6580.3	131.5 = 2×65.0
10	10	6427.2	
8	10	6490.1	62.9 = 1×62.9
8	10	6490.9	63.7 = 1×63.7
8	10	6557.1	129.9 = 2×65.0
8	10	6557.4	130.2 = 2×65.1
8	10	6624.2	197.0 = 3×65.7
8	10	6602.9	205.7 = 4×66.4
6	10	6761.9	334.7 = 5×67.7

SUMMARY

We are now in a position to summarize the results of the analyses of all these different spectra and see what general conclusions can be drawn regarding the nature of the vibrating system which gives the



RESONANCE AND MAGNETIC ROTATION SPECTRA OF SODIUM VAPOR

fluorescence in the region examined. The following table (p. 371) is both a compendium of all the properties of the different series which have been discussed and a numerical guide to the chart of resonance spectra. Nearly all the series have a line between λ 5140– λ 5190 which has been taken as a typical line of the series, and determined the order in which they have been arranged. For convenience the magnetic rotation series have been denoted by M and the white-light fluorescence series by F . The stimulations due to zinc, bismuth, thallium, and the shorter cadmium line have not been discussed. Except in the case of thallium the resonance spectra produced usually consists of a fairly regular group in the violet and a complicated spectrum in the yellow-green which in no case has been satisfactorily arranged in series with some lines in the intervening region. The green thallium line λ 5350 gives a series from λ 5200 to λ 5400 in which the lines are about 37 Å. U. apart. But as all these resonance spectra seem to be radically different from the other resonance spectra already described they are omitted from the present discussion.

It might appear that in the case of the more complicated spectra there was a certain arbitrariness in picking out the lines which belong together. There is no question about the series-grouping in silver, lead, or lithium excitations. These series can be used to check the arrangement of the magnetic rotation lines. The latter, in turn, aid us in picking out new series in more complex spectra, such as in the magnesium and copper excitations. It rarely happened that there was a choice between two lines. If there was, the one which gave the best value for the common difference was adopted. By this mode of classification each series acts as a check on the others and they probably in all cases do represent lines which are physically related. Upward of 200 lines have been obtained in the resonance spectra described above and of these almost two-thirds have been classified into series.

It was somewhat of a disappointment to find that even with the new measurements the common difference k is not an absolute constant. The divergencies from a constant value are not systematic. It is possible they may to a certain extent, not exceeding 0.5 Å. U., be accounted for by errors of observation in the case of faint lines. Most of the lines whose relative intensity is marked "2" were so

faint that they were barely visible under the microscope of the dividing engine, but even making allowance for this source of error the discrepancies, in some cases, are too large to disappear entirely as in the case of the magnesium and copper series. Since these departures from the law of equi-spacing are not systematic they cannot arise from the fact that this law is an approximation but they must be in the nature of disturbances. In fact it would be surprising if such a complicated vibrating system as we must have here could emit radiations whose wave-lengths would be exactly represented by such a simple law. Slight apparent shifts may also arise from the presence of a strong absorption line, for the fluorescent light is obliged to pass through cooler sodium vapor on its way to the spectroscope, as has been pointed out in an earlier paper.

The dynamical model of the sodium fluorescence proposed by Stephenson suggests that the differences of the frequencies of the lines in the same series should be constant. But a simple trial for such a series as silver α proves immediately that this relation does not hold. The variations are very much greater than before. We conclude therefore that the formula which most nearly represents the lines in a series is

$$n = \frac{1}{\lambda} = \frac{1}{\lambda_0 + xk} = \frac{k}{\lambda_0/k + x} = \frac{No}{u + m}$$

There is an obvious resemblance to the ordinary formula for spectrum series.

Though we cannot accept the dynamical model suggested by Stephenson, still it is an interesting analogy. It is probable that the series are due to some cyclic electromagnetic system such as a ring of electrons in orbital motions, and that the differences of the wave-lengths in the series bear some relation to the period of the cyclic motion.

Even the average value of k for each series is not a constant, as will be seen from the table, in which it varies from 38-39. The different series should therefore get slightly out of step when they are plotted on the chart, but the effect is not noticeable. The difference in the value of k is because the series only coincides for a small part of the spectrum; and the differences have been taken over different parts of the spectrum and from a different origin in each case. Where

two series have corresponding members at any point they will be found to remain very closely in step with each other all along the spectrum until one series disappears. We say therefore that all these series approximate to an ideal type in which the spacing is uniform for every series.

Series	<i>k</i>	No. of Lines	Exciting Line	Typical Line	First Line	Last Line
<i>M</i> 5.....				5148		
<i>F</i> 5.....				5148.3		
Lithium.....	<i>c</i> 37.5	6	4972.1	5152.8	5192.8	5303.3
Copper.....	<i>b</i> 38.4	9	5153.4	5153.4	4885.8	5230.9
Lead.....	<i>b</i> 39	6	5006.5	5158.5	4964.4	5158.5
Cadmium.....	<i>d</i>	4	5086	5159		
<i>M</i> 1.....				5159.1		
<i>F</i> 1.....				5159.7		
Silver.....	<i>b</i> 38	4	5209.2	5160	5122	5236
Barium.....	<i>b</i> 38.3	6	4932	5161.6	5123.9	5318.5
Lead.....	<i>a</i> 39	10	5006.5	5162.4	4929.4	5278.8
Lithium.....	<i>b</i> 38.4	2	4972.1	5162.4	5124	5162.4
Copper.....	<i>d</i> ₁ 38.4	5	5105.7	5163	5086.7	5279.2
Cadmium.....	<i>b</i>	7	5086	5164.4		
<i>M</i> 2.....				5165.8		
<i>F</i> 2.....				5166		
Lithium.....	<i>a</i> 38.7	7	4972	5167.3	4934.5	5167.5
Magnesium.....	<i>a</i> 38.9	9	5167.5	5167.5	5050	5244
Barium.....	<i>a</i> 38.3	12	4934	5167.8	4860.9	5321.3
Copper.....	<i>d</i> ₂ 38.5	6	5105.7	5168.5	5130.5	5322.2
Cadmium.....	<i>c</i>	6	5086.2	5169.5		
Silver.....	<i>a</i> 38.3	11	5209.2	5170.8	4947.5	5324.5
Magnesium.....	<i>b</i> 38.5	12	5172.9	5172.9	4865.8	5249.2
<i>M</i> 2.....				5172.9		
<i>F</i> 3.....				5173.1		
Copper.....	<i>c</i> 38.4	7	5218.5	5179.3	4873.8	5256.2
<i>M</i> 4.....				5179.6		
<i>F</i> 4.....				5180.1		
Copper.....	<i>a</i> 38.1	9	5105.7	5181.8	4878.9	5181.8
Magnesium.....	<i>c</i> 38.1	5	5183.8	5183.8	4842.3	5300.8
<i>M</i> 5.....				5186.5		
<i>F</i> 5.....				5186.9		

An attempt has been made to group all these series into one comprehensive scheme. The arrangement of the resonance spectra into series has an intimate connection with the regularity which has already been noticed in the spectra of the white-light fluorescence and magnetic rotation in the same region (λ 4900– λ 5300). In this interval we find that both spectra consist of five series of lines and bands respectively, in step with the resonance spectra. If we assume that the series are due to the forced oscillations of a cyclic system, then

the lines in each band would correspond to the different frequencies of the system, each of which gives an equally spaced series, so that the band would recur at equal intervals along the spectrum, which depend on the period of the cyclic motion. If we take the table of all the series, we see that, on this scheme, the series lithium *c*, copper *b*, lead *b*, and cadmium *d* all belong to the band which corresponds to the fifth magnetic series, and so on for the other series.

This fluorescent band should be the complement of the corresponding portion of the absorption spectrum. We do not, however, observe any periodicity in the absorption spectrum of sodium vapor in vacuo, but at atmospheric pressure the spectrum becomes fluted and these flutings correspond exactly to the white-light fluorescent bands. They are produced by the increase of the absorption in that part of the spectrum which corresponds to the head of the fluorescent band.

This phenomenon is no doubt connected with the magnetic rotation which takes place only at the head or tail of a band. It has been shown that the magnetic rotation in the lines which are members of any of the magnetic series is in the same sense as at the D lines, which are due to negative electrons. It would, however, be an unwarranted extension of elementary theory to assert that the fluorescent lines are all due to negative electrons, but it is probable that they are.

If we make the assumption that each band corresponds to one vibrating system we must assume that the different bands are interconnected; for a monochromatic stimulation sets two and even three series going which are each in different bands. This will be seen from the chart or the table. The lithium and barium excitations are good examples of this. They excite three series, *a* in the second band, *b* in the first band, *c* in the fifth band. In the detailed discussion it was shown that these two resonance spectra were very similar and were doubtless due to the same system or combination of systems.

This is the only experimental connection which has been observed between the series. The hypothesis that the lines in one band belong to the same system is questionable. But the economy of thought attained by the representation of the phenomena by the above scheme makes it worthy of consideration.

JOHNS HOPKINS UNIVERSITY
BALTIMORE, MD.

BIOGRAPHY.

Felix Edward Hackett was born in Omagh, County Tyrone, Ireland, on August 16th, 1882. He received his early education in the schools of his native town. In September, 1898, he entered University College, Dublin. He held a first class mathematical scholarship in the Royal University of Ireland, 1900–1902, and graduated from University College in the same university in October, 1902, with the degree of B. A. with first class honours in Experimental Physics and Chemistry. In the following year he obtained the degree of B. Sc., with first class honours in Mathematical Physics and Experimental Physics. In October, 1904, he won a studentship in Experimental Physics and Chemistry with the degree of M. A., and in 1905 a junior fellowship in Natural Philosophy. He has published papers on: The Photometry of n -rays, R. D. S. Trans., September, 1904; The Ionic Theories of Magnetic Rotation, Proc. R. I. A., July, 1906; and in conjunction with J. A. McClelland on: The Secondary Radiation from Compounds, R. D. S. Trans., 1906; The Absorption of B. Radium Rays by Matter, R. D. S. Trans., 1907. During the years 1906–1907 he was lecturer in Mathematics in University College, Dublin, and examiner in Mathematical Physics and Experimental Physics in the Royal University of Ireland. In March, 1907, he was elected a member of the Royal Irish Academy. In November, 1907, he entered Johns Hopkins University and became a candidate for the Ph. D. degree, taking Physics as his principal subject with Physical Chemistry and Mathematics as subordinate subjects.

